HYDROGEN: *EVERYTHING A CITY NEEDS TO KNOW*

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ENERGYCITIES

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ABOUT

Energy Cities is a network of 1,000 local governments in 30 countries. We believe that the energy transition is about more than renewable energy or great technologies. It is about a wise use ofresources while strengthening localparticipation and well-being in a democratic Europe.

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INTRODUCTION

Hydrogen has long been identified as an alternative to fossil fuels. First in the 70s, especially in Japan, and then again in the 2000s. **But the most recent "hydrogen hype" is different:** technology is more advanced and costs are dropping.

There is a **clear political window** today at the European level to introduce hydrogen as part of the fit for 55 package and some Member States have included hydrogen in their COVID recovery plans. It is therefore an **economic opportunity** for several industries such as the ones usinghydrogen as a raw material (chemical and steel industries e.g.).

Energy Cities wants to bring the debate to the local level to understand **how hydrogen can help decarbonise cities and what are the challenges for local governments.** Cities need to know what the European hydrogen strategy will be, how they can rely on it for part of their energy consumption and how hydrogen will be supplied and transported for their own future plans.

KEY FINDINGS

- Hydrogen can be a key technology to help decarbonise hard-to-abate sectors in cities such as heavy industries or transport (marine shipping, trains). Hydrogen can also have a role to provide dispatchable/on-demand energy to balance power grids in cities. Policies to prioritize its use in these sectors need to be developed.

- Hydrogen is not the silver bullet to decarbonise heating in cities: it is not efficient, competitive or easy to use hydrogen for home heating. Cities will bet on a range of several fossil free solutions depending on the local context and resources to decarbonise their heating sectors such as district heating and heat pumps, renovation to increase energy efficiency, waste heat recovery, solar thermal and geothermal energy, smart appliances etc.

- Only green hydrogen can be considered as clean and must be developed in the EU. Other types of hydrogen involve life-cycle GHG emissions and may contribute to the perpetuation of fossil fuel use. Green hydrogen will be a scarce premium product and likely expensive.

- Hydrogen would require huge investments to bring the gas to cities via pipelines: the current gas network would need to be refurbished to support 100% hydrogen. The costs of investments and the feasibility of the pipelines' refurbishment is likely underestimated. Thus, local production and consumption should be prioritized.

WHAT ARE THE DIFFERENT TYPES OF HYDROGEN?

NATURALLY OCCURRING WHITE

Hydrogen (H) is the lightest element of the periodic table and the most common substance in the universe. It can be used as feedstock, fuel or energy carrier and does not emit CO_2 when burnt, that is why you often hear about its high potential for decarbonising our economy. In nature, we find it mostly in gaseous form (H_2) and it is colourless. That is why, when you hear about "white hydrogen", we refer to **the naturally occurring one** that might be (rarely) found in underground deposits.

We don't have any viable strategy to use these deposits now, so we apply different processes to **generate it artificially**. That is what the colours are for: each one refers to the energy source and/or process that was used to produce hydrogen.

THE NAME SAYS IT ALL BROWN/BLACK

The oldest way of producing hydrogen is **by transforming coal into gas.** Gasification processes convert organic or fossil-based carbonaceous materials into carbon monoxide, hydrogen, and carbon dioxide. Gasification is achieved at very high temperatures (more than 700°C), without combustion, with a controlled amount of oxygen and/or steam. The carbon monoxide then reacts with water to form carbon dioxide and more hydrogen via a water-gas shift reaction.

The gas generated via coal gasification is called syngas and the hydrogen can be separated from the other elements using absorbers or special membranes. This hydrogen is known as brown or black depending of the type of coal used: brown (lignite) or black (bituminous) coal. It is the result of a **highly polluting process** since both CO_2 and carbon monoxide cannot be reused and are released in the atmosphere.

HYDROGEN FROM BIOMASS

Biomass can also be transformed to produce hydrogen via **gasification**. Depending on the type of biomass but also on the use of carbon capture and storage technologies, the net carbon emissions can be lower than brown or grey hydrogen.

WHAT ARE THE DIFFERENT TYPES OF HYDROGEN?

THE MOST COMMON ONE GREY

Most hydrogen nowadays comes **from natural gas:** it is bonded with carbon and can be separated from it via a process involving water called "steam reforming", but the excess carbon generates CO_2. This hydrogen is called grey whenever the excess CO_2 is not captured. Grey hydrogen **accounts for** ***most of the production today*** and emits ***about 9.3 kg of CO_2 per kg of hydrogen production.*** Sometimes, hydrogen is referred to as "grey" to indicate it was created from fossil fuels without **capturing the greenhouse gases** and the difference with brown or black hydrogen is just in the smaller amount of emissions generated in the process.

... IF YOU PUT THE EMISSIONS UNDERGROUND BLUE

Hydrogen is considered blue whenever the emission generated from **the steam reforming process are captured and stored underground via industrial carbon capture and storage (CCS),** so that it is not dispersed in the atmosphere. That is why blue hydrogen is often considered a carbon neutral energy source, even though **"low carbon"** would be more accurate since ***around 10-20% of the generated CO^2 cannot be captured***. Furthermore, from a life cycle perspective, blue hydrogen, which requires natural gas, generates much more emissions. Indeed, there are **methane leaks** during the extraction of natural gas and its transport, while fossil methane has a high global warming potential (about 30 times higher than CO^2).

SOLID CARBON AS A BY-PRODUCT TURQUOISE

A new way of extracting hydrogen **from natural gas** is currently in experimentation phase. The gas can be decomposed at very high temperatures generating hydrogen and solid carbon thanks to a process called methane pyrolysis. This hydrogen is then referred to as "turquoise" or low carbon-hydrogen.

WHAT ARE THE DIFFERENT TYPES OF HYDROGEN?

If the hydrogen is the result of a process called water **electrolysis**[1] – that is using electricity to decompose water into hydrogen gas and oxygen, then we can talk about: **pink**, **yellow** or **green hydrogen**.

In this case, the full life-cycle emissions of this electricity-based hydrogen production, depends on how the electricity is generated:

FROM NUCLEAR ENERGY PINK

The colour pink is often used for hydrogen obtained from electrolysis through **nuclear energy.**

USING A MIX OF WHATEVER IS AVAILABLE YELLOW

The colour yellow sometime indicates hydrogen produced via electrolysis through **solar power**, but often is also used to indicate that the electricity used for the electrolysis comes from **mixed sources based on availability** (from renewables to fossil fuels).

FROM RENEWABLES GREEN

Often also called **"clean hydrogen"**, green hydrogen is produced using electricity generated from **renewables** and currently accounting for around 1% of the overall hydrogen production. That is the only hydrogen colour we can consider as clean. Also, the European Commission intends to scale up its production.

GREEN HYDROGEN IDENTITY CARD

ADVANTAGES

- It can be produced, stored, transported and used without toxic pollution or CO_2 emissions (only emits water), and can be produce anywhere there is electricity and water,
- It can adapt to a variety of uses: it can generate heat or electricity,
- Hydrogen carry three times more energy per unit of weight than petrol, diesel or aviation fuel.

DISADVANTAGES

- Lot of energy is needed to produce it (driving down the efficiency).
- It requires extreme conditions to be stored as a liquid (highly compressed and refrigerated to −253°C).
- It can weaken the metal, escapes through the smallest leaks and it can explode.
- It transports less energy power per unit than others fuel ex: natural gas (as liquid or gas form).

[1] There are almost as many types of electrolyser technologies for green hydrogen as there are colours of hydrogen. Davine Janssen from Euractiv.com has a thorough look at the different approaches in China and the EU.

THE EU STRATEGY TO DEVELOP THE HYDROGEN PRODUCTION AND INFRASTRUCTURE

The European Commission published the ***European Hydrogen Strategy*** in July 2020. It foresees **3 successive and gradual phases to develop the hydrogen economy.** Regarding the need for infrastructure, each phase reflects the different hydrogen uses and market outlook at the time. In total, the Commission plans to invest €65 billion for hydrogen transport, distribution and storage, and hydrogen refuelling stations for vehicles.

1. FIRST PHASE 2020-2024: LOCAL HYDROGEN PRODUCTION AND LIMITED INFRASTRUCTURE NEEDS

In the first phase, the European Commission aims **to decarbonise the sectors that are already using hydrogen such as the chemical industry, and new sectors** (heavy-duty transport) and industrial processes. The strategy relies on green hydrogen, but also on "low carbon hydrogen" (produced from any kind of electricity or fossil fuels with carbon capture) to kick off the demand. The hydrogen will be first produced on site with the installation of 1GW electrolysers next to the industrial clusters, using existing renewables capacity and infrastructure. **The goal is to produce 1 million tons of renewable hydrogen by 2024.**

Hydrogen can be transported as gas via pipelines (more advantageous for large demand) or trucked as liquid or gas (convenient for low demand). As in this first phase production will be local and mainly using existing connections, the **"infrastructure needs for transporting hydrogen will remain limited"**: short pipelines or trucks for the last kilometres and infrastructures for carbon capture.

ENERGY CITIES' OPINION ON THIS FIRST PHASE

This first phase looks appropriate, **targeting mainly the heavy industry sector that cannot be electrified.** The production on site avoids **important** ***energy losses*** (multiple conversion in other carriers, important energy inputs to move hydrogen in the pipelines with compressors ...) and reduces the infrastructure investments costs.

Nevertheless, we are concerned that the European Hydrogen Strategy enhances the use of ***blue hydrogen***. Indeed, carbon capture infrastructure can be very expensive and can ***absorb at most 90% of carbon emissions.*** Today, the cost of green hydrogen is not competitive with blue hydrogen – unless we take into account the negative externalities (environmental cost of pollution) - but it should be the case ***by 2030*** with a strong policy incentive.

Another concern is the promotion of **blended hydrogen** as a temporary solution. It may imply ***some extra cost and adjustments at the consumer ends,*** and help perpetuate the use of fossil fuels.

NATIONAL HYDROGEN PLANS

Some Member States already published a national hydrogen strategy in 2020 such as ***France***, the ***Netherlands***, ***Germany*** or ***Spain*** as a part of their national recovery plans. These strategies aim to scale up the production in the next decades and focus on so-called "clean hydrogen" (this vague term includes both green and blue hydrogen). However, the German plan foresees public subsidies only for green hydrogen.

2. SECOND PHASE 2025-2030: THE RAISE OF A EUROPEAN HYDROGEN MARKET AND NETWORK

The demand for hydrogen will rise sharply during this second phase. The Commission plans to increase production capacity (10 million tons of renewable hydrogen by 2030) and to import hydrogen from neighbouring countries (North Africa, Ukraine). In parallel with local production in "Hydrogen Valleys", the European Commission expects the need for a **long-distance transportation infrastructure to emerge.** The Gas for Climate consortium has envisioned a ***"European Hydrogen Backbone"***: 23 000km of hydrogen pipelines by 2040 crossing the European continent. This giant network would be 25% new built pipelines and 75% former natural gas pipelines converted in hydrogen-compatible ones. They estimate a total investment cost of 25 to 64 billion euros.

3. THIRD PHASE 2030-2050: A LARGE SCALE AND MATURE TECHNOLOGY AND NETWORK

The European Commission foresees **large-scale deployment of hydrogen by 2030**, in all sectors that are difficult to decarbonise, including aviation and long-distance shipping. The market will be more mature and globalised and the price of green hydrogen will be competitive. The infrastructure will continue to build on the momentum generated by the phase 2 and green ammonia will be a more widespread mean of transporting hydrogen over very long distances as well as powering aircraft and ships.

ENERGY CITIES' OPINION ON THE SECOND AND THIRD PHASES

The long distance pipelines infrastructure could present some advantages as it allows to scale up hydrogen production to meet the need of the hard to abate sectors and to produce hydrogen where ***renewable energy is cheaper*** due to the abundance of solar and wind resources.

Nevertheless, **we need to be careful and plan wisely the infrastructure development following a "no regret" strategy.** Indeed, the risk is to overestimate the future hydrogen demand and face unnecessary additional costs and significant ***energy losses*** when transporting the hydrogen over long distances. "Co-planning investments in the field of hydrogen with the location of renewable energy supply or industrial demand offers the possibility of reducing costs by reducing by 60% the amount of infrastructure required for hydrogen" ***explained Lisa Fischer and Elisa Giannelli*** from E3G. Agora Energiewende completed a ***really good*** mapping of the "no regrets" demand clusters and infrastructure in Europe.

Moreover, the hydrogen backbone strategy **must not leave an open door to the use of hydrogen in sectors where other solutions are already available,** such as home heating and low-temperature industrial heat demand, nor a way to ***perpetuate the profit of the gas industries.***

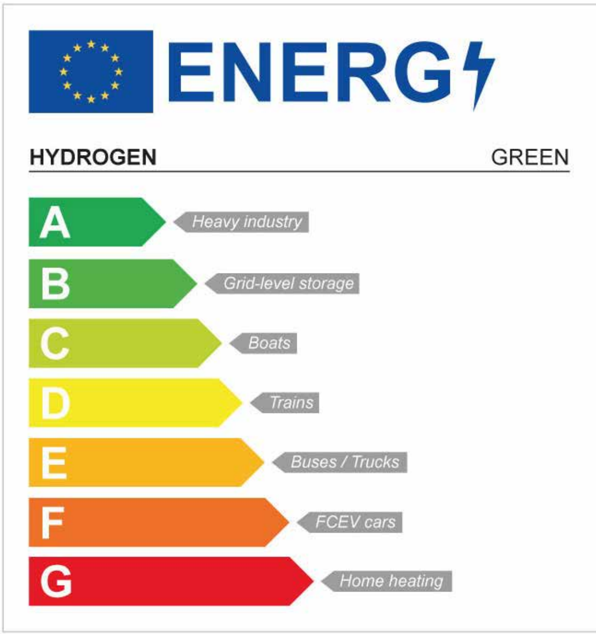
Europe should prioritise regional and local hydrogen production as much as possible, to avoid long transport, allow consumers to know where their hydrogen comes from and ensure the development of skills and jobs in Europe. The creation of a large and international hydrogen market doesn't match with **the subsidiarity principle** which should apply for energy and heat in particular. It could lead to the replacement of current imports of fossil fuels with the import of low-cost green hydrogen from countries producing low-cost green electricity (e.g. North Africa, but also Middle East), which will not reduce the energy bills of European territories nor increase the security of supply.

THE DIFFERENT USE FOR HYDROGEN IN CITIES

Hydrogen is being touted as a solution to many challenges in the energy transition. And it is an exciting and flexible energy carrier that will be key to the EU's goals of ***energy system integration***. **But hydrogen is clearly better suited to some challenges more than others.**

It will depend on how the technology and its costs evolve compared to other decarbonised solutions. Also, specific local conditions like access to large amounts of renewable energy, industrial hubs and geological formations for large-scale storage will also dictate where and when green hydrogen makes sense[2]. We haven't looked at some much-touted uses of green hydrogen, chemical feedstock, maritime shipping and aviation, as these fall outside of what cities can generally control.

You can find below a **guide of where we think it will fit best in cities, from the best to the worst use, with a special emphasis on home heating as it is the most controversial point and the one that can have the bigger impact on city organization.**



Using green hydrogen efficiently means using it where direct electrification isn't an option (Image © Energy Cities)

1. HEAVY INDUSTRY

The closest thing to a consensus about hydrogen is that it's greatest potential is the decarbonisation **of *heavy industry* – especially *steel* but also *refineries*, *cement*, ceramics and chemicals.** Essentially, any industry that needs extremely high temperatures. Some of these industries could be electrified but that would require a big investment in completely new equipment whereas green hydrogen could serve as an almost direct replacement for coal and gas.

[2] For a more complete overview on hydrogen this article by ***Carbon Brief is excellent.***

2. GRID-LEVEL STORAGE

One of the biggest challenges of a renewable electricity grid is the difference between summer and winter generation – especially as you go further north. **Creating green hydrogen from ample solar generation in summer (or wind when demand is low) for use in the winter is one possible solution *(Michael Liebreich of BNEF runs through some numbers here)*.** Electricity from green hydrogen will have a much higher marginal cost. But this is less important for three reasons:

- ✓ Overall system costs of a largely renewable grid should be lower
- ✓ All intermittent energy sources such as gas peaker plants have higher marginal costs
- ✓ Electricity from green hydrogen is seen as a solution for the 'last mile' of grid decarbonisation – a cold and windless week in January – and not a substantial player in the grid year-round.

Hydrogen could of course be used to **balance district heating grids in cities** in addition of balancing power grids, and even more efficiently if both balances are coupled.

3. BOATS

Big **or** ***small, hydrogen*** **and** ***electric battery boats*** **are coming.** The trade-off between the space needed for hydrogen and the weight of batteries as well as use patterns will play a big role in determining which technology might work best. Ports also look like a likely spot for the development of hydrogen hubs so hydrogen might prove quite popular on the water.

4. TRAINS

Trains must be the most prominent electrified transportation option – normally with overhead wires. But where overhead wires aren't cost-effective, or possible, there are ***more and more hydrogen powered trains*** as well as combined battery/hydrogen trains and ***lots of battery electric trains***. **All of these options will likely co-exist for decades to come** as different distances and use patterns (not to mention accessibility of green hydrogen) make one option preferable to the others.

5. BUSES AND LOCAL HEAVY DUTY (CARGO/GARBAGE TRUCKS)

Battery-electric and hydrogen fuel cell buses are ***spreading rapidly in Europe*** although still lagging far ***behind China where 99%*** of the world's electric buses can be found. Both models have zero tailpipe emissions, helping address local air pollution. But the mass manufacture of electric buses, easier infrastructure investments and avoiding the energy loss of electrolysis means battery electric buses should be preferred. Hydrogen fuel cell buses do have the advantage of rapid refuelling, but with sufficient range electric buses can be charged overnight and those large batteries can play an important role in meeting demand peaks with vehicle-to-grid technology.

For local heavy duty (cargo/garbage trucks), we see a **clear benefit for electric trucks over hydrogen fuel cell vehicles.** The range is easily covered by today's batteries and with ***big commercial manufacturers*** now involved life is simpler and easier with a battery-electric vehicle. As with buses the infrastructure is easier, and the prospect of vehicle-to-grid technologies in the future mean the financial equation will only get better.

6. FCEV (CARS AND LIGHT TRUCKS)

This is a big no for hydrogen. There is a reason most of the ***EU's car manufacturers have bowed out of the hydrogen market.*** Battery electric vehicles are much further along in their development, available in a wide variety of styles and price points and the availability of green hydrogen as a cheap commodity is decades away.

New research from Transport and Environment "shows that powering just a fraction of vehicles with e-fuels (including e-diesel and hydrogen) in 2050 would require new offshore wind-farms covering an area the size of Denmark."

7. HOME HEATING

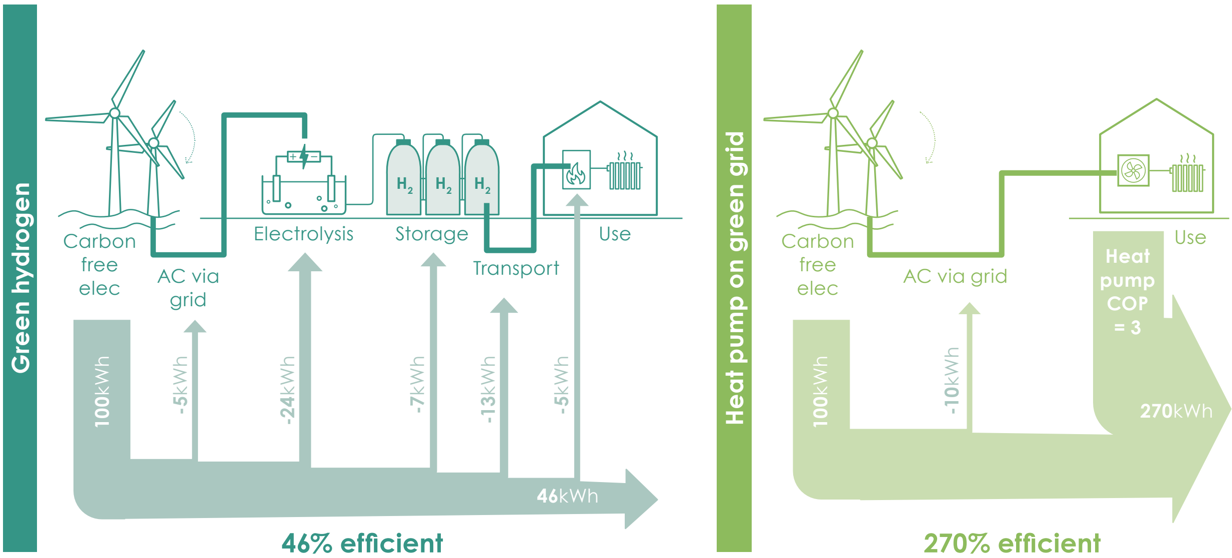
There's an appealing logic to using hydrogen in home heating. Just inject a little into the gas mix and emissions go down without any disruption. Unfortunately, most experts are quite clear this is a bad idea as explained in the following sections.

WHY IS HYDROGEN FOR HOME HEATING NOT THE BEST OPTION?

Hydrogen is often presented as a quick fix to get rid of fossil fuels for heating and cooling in cities. But it is widely debated by experts and has some **uncertainties and risks of lock-in effects.** In this paragraph we will therefore question this statement point by point.

IS HYDROGEN EFFICIENT?

Green hydrogen requires ***five times*** **more electricity to heat a home than a heat pump.** In other words, hydrogen-based low-temperature heating systems consume ***500 to 600%*** more renewable energy than heat pumps. Indeed, the transport, storage, multiple stages transformation and combustion of hydrogen lead to **multiple losses.**



The difference of efficiency between green hydrogen and a heat pump supplied by a green grid (Source: ***LETI hydrogen Report***, Data source: Prof David Cebon)

IS HYDROGEN COST-COMPETITIVE?

The cost competitiveness is relative and data must be compared with the different low carbon alternatives to heat cities: heat pumps, district heating, and hydrogen boilers. The cost analysis differs greatly according to the criteria used: considering the evolution of hydrogen and electricity prices, estimated temperatures in a few decades, infrastructure, etc.

Scientific studies **conclude that hydrogen is not competitive in heating** as air-source heat pumps are at least **50% lowe**r cost than the hydrogen-only technologies. The ***ICCT*** even concludes that “if natural gas costs were 50% lower or renewable electricity prices were 50% higher in 2050 compared to our central assumptions, heat pumps would still be more cost-effective than hydrogen boilers or fuel cells” which is a very interesting news considering the **social aspects of the energy transition.**

Indeed, as we saw earlier hydrogen-based heating technologies need much more energy than heat pumps and ***a major part*** of the price of green hydrogen is the price of electricity. So, when the price of renewable electricity drops, it will ***be a saving for both electrification and hydrogen.***

Moreover, some experts predict that if hydrogen is used massively for heating **it will** ***double hydrogen costs.*** A shortage of hydrogen would induce competition between different sectors (industry, chemicals, storage) which will push up the prices.

Nevertheless, ***unrenovated buildings*** are the notable exception where hydrogen may be more competitive. But the proposed ***Renovation Wave*** will reduce energy consumption for heat and the proposed Minimum Energy Performance Requirements under the Energy Performance of Buildings Directive (EPBD) would tackle these least-efficient buildings first and erase that potential market.

WHAT INFRASTRUCTURE FOR THE USE OF HYDROGEN IN THE CITY?

Hydrogen has different properties than natural gas. Using 100% hydrogen for heating houses **involves some changes in the network to bring gas into the houses and in the house’s appliance itself.** There are a number of different materials used for ***domestic natural gas pipework***. Consequently, in some houses, the changeover to hydrogen can be quick with only the change of boiler and meter, but in others, it also requires the ***whole appliance to be replaced***. To facilitate this conversion work, which could take several days per house, the gas companies are proposing to install already mixed boilers ready for future hydrogen use.

Research has showed that **many uncertainties remain to be resolved and that beyond the acceptability of hydrogen by owners,** "the inaccessibility of domestic gas pipework could be a significant barrier to conversion if pipework needs to be either fully inspected or replaced as natural gas pipes are sometimes covered by concrete or ducted through inaccessible voids".

Another limitation is the question of **who bears** ***the responsibility and the cost of these transformations.*** Compared to electrification, investments on hydrogen will be riskier and will generate less capital returns given the unproven technology, uncertainties on hydrogen cost and up-scaling needed. As a result, more public and taxpayer investments should be made to finance the construction work.

IS THE USE OF HYDROGEN RATHER EASY OR DISRUPTIVE FOR CITIZENS?

This is an important question, very linked to the infrastructure debate, raised by the gas companies. According to them, **hydrogen is a *"like-for-like"* solution:** Replacing natural gas with hydrogen is a ***painless and effortless solution*** for citizens. ***This non-disruptive argument*** is very attractive for policy-makers. Nevertheless, it is vague because the change of gas could lead to an increase in the bill as well as a replacement of the infrastructure at the ***inhabitant's home*** (***boiler, in-house pipelines,*** cooking stoves) and in his street (pipelines and compressors).

WHEN WILL THE HYDROGEN TECHNOLOGY BE READY TO HEAT CITIES?

Analysing the UK projects and market, ***Centrica***, the biggest gas supplier, admits that it will take more than ten years to produce green hydrogen for heating. While district heat, heat pump and energy efficiency technologies (to name few of them) are already available. **Waiting for the hydrogen era to arrive for cities could create a terrible lock-in effect for the decarbonisation of heating.**

Regarding the timeline, Jan Rosenow, from Regulatory Assistance Project, ***says*** "Yes, do some research on hydrogen and do pilot projects, but it is a big bet to say hydrogen will solve our problems in 2040 and then not do anything in the meantime. I think that would be irresponsible."

SOLUTIONS TO DECARBONISE HEATING AND COOLING

Are you interested in the strategies to decarbonise heating and cooling in the built-environment? Energy Cities is part of the ***Decarb City Pipes 2050*** project, in which we work with 7 seven cities to develop transition roadmaps to phase-out fossil fuels from urban heating and cooling. Visit the website and sign up to our newsletter to get updates on the project outcomes.

CONCLUSION

Hydrogen is a **very exciting technology** that has a real potential to help the European Union meeting its climate neutral target by 2050. Indeed, it will play a key role in decarbonising hard-to-abate sectors when produced from renewable electricity.

Nevertheless, **hydrogen is expensive and wasteful to produce.** It is therefore necessary **to choose carefully** the sectors where we want to develop it and not give in to the pressures of the gas industry. Also, we must correctly assess infrastructure needs so as not to overestimate them and undertake major works that are not necessary.

The European Union should implement a **"no regrets" strategy** choosing the most efficient, affordable and carbon free solutions for each application. Hence, hydrogen should not compete with renewable energies in sectors where they are more efficient. That is in particular the case for buildings heating where heat pumps and district heating are a much more strategic and cost-efficient choice for cities, in parallel with energy efficiency. Cities need to have their say in the development of the hydrogen infrastructures so that these investments are in line with their industrial, urban and energy strategies, to ensure a just and fair transition.

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